

TITLE OF THE INVENTION

ACTIVATED CARBON FOR ELECTRIC DOUBLE LAYER CAPACITOR

5 FIELD OF THE INVENTION

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The present invention relates to an activated carbon for electric double layer capacitor having excellent durability, and more particularly to an activated carbon for electric double layer capacitor, which permits providing an electric double layer capacitor exhibiting a high electrostatic capacity and a low resistance and excellent in both retention of electrostatic capacity and retention of resistance after a durability test when polarizable electrodes of the electric double layer capacitor are constructed by the activated carbon. The present invention also relates to activated carbon electrodes formed with the activated carbon exhibiting such excellent durability as described above, and an electric double layer capacitor equipped with the activated carbon electrodes as polarizable electrodes.

BACKGROUND OF THE INVENTION

An electric double layer capacitor is characterized by large capacity and long life, possible quick charge, easy charge and discharge, excellent cycle properties compared with a secondary battery and lower

price than an Ni-Cd battery having the highest reliability among secondary batteries. Therefore, its functional applications are expected as a new energy device in many fields. The electric double layer capacitor is investigated so as to apply it to a high power field such as auxiliary power source for electric cars and hybrid cars, including a low power field such as a back-up power source for electronic instruments. Therefore, there is a demand for development of higher-performance polarizable electrodes.

The electric double layer capacitor is a large-capacity capacitor making good use of a capacity stored in an electric double layer occurred at an interface between polarizable electrodes and an electrolyte. The polarizable electrodes are required to have large specific surface area and high bulk density, be electrochemically inert and have low electrical resistance. An attention has been attracted to activated carbons as electrode materials satisfying these requirements, and an electric double layer capacitor equipped with polarizable electrodes formed with such an activated carbon has been already developed.

As activated carbons used for forming polarizable electrodes, it has been proposed to use activated carbons obtained from various carbonaceous raw materials such as coconut shells, petroleum pitch, petroleum coke, phenol resins, polyvinylidene chloride resins and

polyvinyl chloride resins. Activated carbon is generally produced by carbonizing a carbonaceous raw material and then activating the carbonized product to make it porous. The activated carbon has countless minute holes called pores and a large surface area (also referred to as specific surface area), and the large surface area is utilized as a polarizable electrode.

As described above, the activated carbon has properties suitable for used as a material for polarizable electrodes of the electric double layer capacitor. However, the activated carbons proposed heretofore have not been sufficient in durability when they have been formed into polarizable electrodes. More specifically, an electric double layer capacitor equipped with polarizable electrodes formed with the conventional activated carbon has involved a problem that the performance is deteriorated due to lowering of electrostatic capacity, rise in resistance and the like during use even when initial properties thereof are good. Polarizable electrode materials for electric double layer capacitors are required to cause no electrochemical reaction with an electrolyte or electrolytic solvent and at the same time undergo no oxidation-reduction reaction by itself even when the resulting electrodes are polarized in an operating voltage region. The electric double layer capacitor is always kept in a voltage-applied state when it is

installed as a back-up power source into an instrument. Therefore, when such a reaction is caused even to a slight extent, the performance is markedly deteriorated upon long-term use.

5 The activated carbon is known to affect the properties of an electric double layer capacitor by its pore size distribution, pore volume and surface physical properties such as amount of a functional group on the surface thereof when it is used as polarizable
10 electrodes of the electric double layer capacitor. As a method for improving long-term reliability on application of voltage, it has heretofore been proposed to decrease the amount of a functional group on the surface of an activated carbon [Hiratsuka et al., DENKI
15 KAGAKU, Vol. 59, No. 7, pp. 607-613 (1991)]. More specifically, according to this literature, as a measure of the amount of the functional group on the surface, attention is paid to the content of oxygen in the activated carbon by elementary analysis, and it is
20 elucidated that a polarizable electrode formed from an activated carbon lower in oxygen content becomes less in performance deterioration by application of voltage. Similarly, there have been proposed methods for improving the long-term reliability of an electric
25 double layer capacitor by using polarizable electrodes formed from a carbon material reduced in the concentration of an acid functional group on the surface

thereof (Japanese Patent Publication No. 56827/1994) or polarizable electrodes formed from an activated carbon treated with a reducing agent to remove oxides present on the surface thereof (Japanese Patent Application
5 Laid-Open Nos. 101980/1993 and 201674/1995).

Even when the polarizable electrodes formed from these activated carbons improved by the prior art are used, however, the durability of the electric double layer capacitors yet remains insufficient, and so such
10 electric double layer capacitors have involved a problem that the performance is deteriorated due to lowering of electrostatic capacity and rise in resistance during use for a long period of time. Besides, the durability cannot be improved by a method of merely adjusting the
15 specific surface area of an activated carbon. Accordingly, there is a demand for still greater improvement in activated carbon under a more increasing demand for development of a higher-performance electric double layer capacitor with the years.

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OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the present invention to provide an activated carbon for electric double layer capacitor having excellent durability.

25 Another object of the present invention is to provide an activated carbon electrode formed with this activated carbon.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 diagrammatically illustrates the relationship between α_s -plots by the nitrogen adsorption method and the rate of FS (filling swing).

5 FIG. 2 diagrammatically illustrates the relationship between the retentions of electrostatic capacity and resistance of electric double layer capacitors obtained in Examples and Comparative Example and the rate of FS.

10 FIG. 3 is a cross-sectional view illustrating an exemplary single cell type electric double layer capacitor.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

15 It is essential for the activated carbon according to the present invention to have a rate of FS (filling swing) of at most 27 cm³/g STP in an α_s -plot by the nitrogen adsorption method. The rate of FS in the α_s -plot by the nitrogen adsorption method in the present
20 invention is defined as an area of a deviation from a line representing the total surface area and passing through the origin in positions below $\alpha_s = 1.0$ when nitrogen α_s -plots for activated carbons are constructed as illustrated in FIG. 1 in accordance with the method
25 disclosed in Setoyama et al., Carbon Vol. 36, No. 10, pp. 1459-1467 (1998).

According to the gas adsorption method, the

information as to the specific surface area, pore volume and the like of a porous carbon material is generally obtained. The adsorption measurement is carried out under conditions of a fixed temperature, and thereby the

- 5 relationship between equilibrium pressures and amounts adsorbed called an adsorption isotherm [axis of ordinate = amount adsorbed, axis of abscissa = relative pressure (P/P_0)] is determined. The measurement is generally performed at a boiling point of molecules to be adsorbed.
- 10 In the case of adsorption of nitrogen molecules typical as a probe, the measurement is carried out at 77K.

A value obtained by dividing an amount adsorbed at each relative pressure by the amount adsorbed at $P/P_0 = 0.4$ in the standard isotherm is defined as an α_s value.

- 15 When the P/P_0 indication is converted into α_s indication, the adsorption isotherm of a sample can be compared with the standard isotherm. When an amount adsorbed at each measurement point of the isotherm to be compared is plotted against an α_s value corresponding to each P/P_0 ,
- 20 an α_s -plot can be constructed.

The total surface area is found from a slope of the line from the origin as illustrated in FIG. 1. An external surface area is found from a slope of an extrapolated line (dotted line) from a high-pressure

25 area. In FIG. 1, there is a region in which measuring points deviate from the extrapolated line. This comes from enhanced surface-molecule interaction or

intermolecular interaction in pores and is classified into F-swing (FS) and condensation swing (C-swing; not appear in the case of FIG. 1). In the present invention, attention is paid to FS shown in FIG. 1.

5 When the axis of ordinate in the α_s -plot is indicated by the amount adsorbed, cm^3/g STP, the unit of the rate of FS is given by cm^3/g STP because the axis of abscissa, α_s is dimensionless. In the above literature, FS is described as being created by a strong molecule
10 adsorption field from very small pore surfaces and mainly dominated by pores having a pore size of at most 0.7 nm. Accordingly, it is considered that when polarizable electrodes are formed with an activated carbon having a rate of FS higher than $27 \text{ cm}^3/\text{g}$ STP, an
15 electrolytic solvent, electrolytes (ions) and the like are strongly bound in pores forming a strong molecule adsorption field, and so a probability of causing reactions such as oxidation and reduction of the electrode material itself becomes high, resulting in an
20 electric double layer capacitor having poor durability. On the other hand, it is considered that an activated carbon having a rate of FS not higher than $27 \text{ cm}^3/\text{g}$ STP has less pores forming the strong molecule adsorption field, and so its reactions with the solvent, ions and
25 the like is lessened, resulting in an electric double layer capacitor having excellent durability.

 In the activated carbon according to the present

invention, the rate of FS is preferably at most 25 cm³/g STP, more preferably at most 23 cm³/g STP. No particular limitation is imposed on the lower limit of the rate of FS. However, the activated carbon according to the present invention can exhibit good results when the rate of FS falls within a range of often 10 to 25 cm³/g STP, particularly 15 to 23 cm³/g STP. The STP as used herein means a standard state (temperature = 0°C, pressure = 1 atm).

As a raw material for the activated carbon, may be used, for example, a carbonaceous raw materials such as a coconut shell, petroleum pitch, coal pitch, petroleum coke, phenol resin, polyvinylidene chloride resin or polyvinyl chloride resin. As a process for producing the activated carbon, may be mentioned a process comprising carbonizing and/or activating a carbonaceous raw material. Examples of an activating method, may be mentioned a gas activating method and a chemical activating method.

As a carbonizing method, may be mentioned a method in which a raw material for activated carbon is calcined at a relatively low temperature of 300 to 850°C using an inert gas such as nitrogen gas, carbon dioxide, helium, argon, xenon, neon, carbon monoxide, a combustion exhaust gas or a mixture thereof. In the gas activating method, the raw material for activated carbon is generally carbonized and then subjected to a catalytic

reaction with a mixed gas of steam, carbon monoxide, oxygen and combustion exhaust gas to activate it. The gas activating method is suitable for coconut shells, pitch materials and the like.

5 In the chemical activating method, the raw material for activated carbon is carbonized and/or activated in the presence of zinc chloride, sodium hydroxide, potassium hydroxide, calcium hydroxide, boric acid, phosphoric acid, sulfuric acid, hydrochloric acid
10 or the like. The carbonization and/or activation is generally conducted under conditions of about 400 to 1,100°C. However, the temperature conditions and the like vary according to the kind of the chemical used. For example, when the carbonization and/or activation is
15 conducted with zinc chloride, it is performed at a temperature not higher than a boiling point (732°C) of zinc chloride. It is preferable to carbonize and activate a polyvinylidene chloride resin with zinc chloride.

20 Only the carbonization may be performed according to the kinds of the raw material for activated carbon and the carbonizing and activating methods. However, it is generally preferable to conduct both carbonization and activation. After the carbonizing and activating
25 treatment, the resultant activated carbon may also be subjected to a secondary or still higher activating treatment as needed.

No particular limitation is imposed on the raw material, production process and the like of the activated carbon according to the present invention so far as the rate of FS thereof is at most 27 cm³/g STP.

5 However, the rate of FS can be controlled within the desired range, for example, by selecting any of such conditions as using a polyvinylidene chloride and zinc chloride, presetting the amount of zinc chloride used rather smaller than the resin, adjusting the amount of
10 water, presetting the carbonizing and activating temperature to a higher temperature in the vicinity of the boiling point of zinc chloride and combining these conditions. However, the present invention is not limited to activated carbons obtained by such specific
15 processes.

No particular limitation is imposed on the surface oxygen content in the activated carbon according to the present invention. However, it is preferably controlled to generally at most about 5%, more preferably at most
20 about 4.5% from the viewpoint of durability. In order to achieve far excellent durability in the activated carbon according to the present invention, the surface oxygen content is preferably controlled to lower than 3%. The surface oxygen content in the activated carbon can be
25 determined by the X-ray photoelectron spectroscopy. It is particularly preferable to control the surface oxygen content in the activated carbon to at most 2%. No

particular limitation is imposed on the lower limit of the surface oxygen content. However, it is generally about 0.1%. Examples of a method for lessening the surface oxygen content in the activated carbon include a method in which a carbonized product obtained by carbonization and/or activation is treated at a high temperature in a nitrogen gas stream.

The activated carbon according to the present invention preferably has a specific surface area of 500 to 5,000 m²/g, preferably 800 to 4,000 m²/g as determined by nitrogen adsorption in accordance with the BET method from the viewpoint of electrostatic capacity. When the specific surface area falls within a range of often 1,000 to 2,000 m²/g, particularly 1,100 to 1,600 m²/g, good results can be yielded.

The activated carbon electrode according to the present invention is formed with the activated carbon according to the present invention. In order to produce the activated carbon electrode, it is only necessary to kneading the activated carbon together with a binder and optional additives such as conductive acetylene black and shape the kneaded product into the prescribed electrode form. Examples of the binder include polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF). More specifically, as examples of a production process of the activated carbon electrode, may be mentioned a process in which a solvent is added

to a mixture composed of an activated carbon, a
conductive material, a binder, etc. to prepare a slurry
mixture, and the slurry mixture is applied to a current
collector by coating or dipping and then dried (for
5 example, Japanese Patent Application Laid-Open No.
64765/1998), and a process in which a sheet obtained by
adding a solvent to a mixture composed of an activated
carbon, a conductive material, a binder insoluble in the
solvent, etc. to conduct kneading and molding and drying
10 the molded product is bonded to the surface of a current
collector through a conductive adhesive or the like, and
the conductor is then pressed and dried by heat
treatment.

No particular limitation is imposed on the
15 electric double layer capacitor according to the present
invention so far as it is an electric double layer
capacitor equipped with the activated carbon electrodes
according to the present invention as polarizable
electrodes. Specific examples of the electric double
20 layer capacitor include that of a structure illustrated
in FIG. 3. FIG. 3 is a cross-sectional view illustrating
an exemplary single cell type electric double layer
capacitor. This electric double layer capacitor is
constructed by tightly enclosing a structure that a
25 separator 2 is held between 2 polarizable electrodes 1,
1 and the resultant laminate is further held between
collecting plates (collecting electrodes) 3, 3, into an

electrolytic solution-containing case 4, 4 through a
packing 5. The electrolytic solution may be either a
nonaqueous solvent type or an aqueous type. In the
nonaqueous solvent type, an electrolyte dissolved in an
5 organic solvent is used. As a typical example of the
nonaqueous solvent type electrolytic solution, may be
mentioned a propylene carbonate solution of $(C_2H_5)_4NBF_4$.

The activated carbon electrodes formed with the
activated carbon according to the present invention are
10 particularly suitable for use as polarizable electrodes
for electric double layer capacitors and exhibit
excellent durability. More specifically, an electric
double layer capacitor equipped with the activated
carbon electrodes according to the present invention as
15 polarizable electrodes can exhibit a retention of
electrostatic capacity of preferably 80 to 110%, more
preferably 85 to 105% and a retention of resistance of
preferably 90 to 125%, more preferably 95 to 120% in a
durability test at a temperature of 70°C and a voltage of
20 2.5 V for 12 hours. Particularly preferably, the
electric double layer capacitor equipped with the
activated carbon electrodes according to the present
invention as polarizable electrodes can exhibit high
durability as demonstrated by both retention of
25 electrostatic capacity and retention of resistance of 95
to 105%.

ADVANTAGES OF THE INVENTION

According to the present invention, there are provided activated carbons for electric double layer capacitors, which permit providing electric double layer capacitors exhibiting a high electrostatic capacity and a low resistance and excellent in both retention of electrostatic capacity and retention of resistance after a durability test when polarizable electrodes of the electric double layer capacitors are constructed by the activated carbons. According to the present invention, there are also provided activated carbon electrodes formed with such an activated carbon, and electric double layer capacitors equipped with the activated carbon electrodes as polarizable electrodes.

EMBODIMENTS OF THE INVENTION

The present invention will hereinafter be described more specifically by the following Examples, and Comparative Example. However, the present invention is not limited by these examples.

The evaluation of properties were conducted in accordance with the following respective methods.

(1) Rate of FS:

A nitrogen adsorption isotherm at 77K of each activated carbon sample was determined by means of a high speed specific surface area pore size distribution measuring apparatus [ASAP2000 manufactured by Shimadzu

Corporation], an α_s -plat is constructed from the adsorption isotherm thus obtained in accordance with the method disclosed in Carbon, Vol. 36, No. 10, pp. 1459-1467 (1998), and the rate ($\text{cm}^3/\text{g STP}$) of FS (filling swing) was found as an area of a deviation from a line representing the total surface area and passing through the origin as illustrated in FIG. 1.

(2) Surface oxygen content:

The surface oxygen content in each activated carbon sample was determined by the X-ray photoelectron spectroscopy.

(3) Durability:

Polarizable electrodes were produced with each activated carbon sample, and an electric double layer capacitor equipped with the polarizable electrodes was then fabricated to measure its electrostatic capacity and resistance. With respect to the measurements of the electrostatic capacity and resistance, the respective initial values and values after treated at a temperature of 70°C and a voltage of 2.5 V for 12 hours were found to calculate out the respective retentions. The retentions (%) were expressed as $[(\text{Physical property value after treatment} / \text{Physical property value before treatment}) \times 100]$. A retention nearer 100% indicates better durability.

(4) Electrostatic capacity:

The total discharge energy (W·s) was found as an

integral value of time of discharge energy (discharge voltage x electric current) from a discharge curve (discharge voltage-discharge time) of each electric double layer capacitor to determine the electrostatic capacity in accordance with the following equation:

Electrostatic capacity (F) =

$$\frac{[2 \times \text{Total discharge energy (W}\cdot\text{s)}]}{[\text{Discharge stating voltage (V)}]^2}$$

(5) Resistance:

10 A line was drawn between 2 points at which the voltage was reduced to 75% and 50% of the discharge starting voltage in the above discharge curve (discharge voltage-discharge time) to determine a potential by extrapolating it to zero minute from the starting of
15 discharge. The potential determined by the extrapolation was subtracted from the discharge starting voltage 2.3 V to regard the value thus obtained as voltage drop upon starting of discharge. The voltage drop was then divided by a discharge current to regard the value thus obtained
20 as a resistance value.

(6) Specific surface area:

V_m was determined by a single-point determination (relative pressure x = 0.3) by nitrogen adsorption at a liquid nitrogen temperature using an approximate
25 expression: $V_m = 1/[V(1 - x)]$ derived from the BET equation to find the specific surface area of each activated carbon sample by nitrogen adsorption in

accordance with the BET method from the following equation:

$$\text{Specific surface area} = 4.35 \times V_m (\text{m}^2/\text{g})$$

wherein V_m is an amount (cm^3/g) adsorbed necessary for
5 forming a monomolecular layer on the surface of the
sample, V is a found amount (cm^3/g) adsorbed, and x is a
relative pressure.

More specifically, the amount of nitrogen adsorbed
on the activated carbon sample at a liquid nitrogen
10 temperature was measured by means of Flow Sorb II 2300
manufactured by MICROMERITICS Co. in the following
manner. An activated carbon ground to a particle size of
about 5 to 50 μm is charged into a sample tube, and the
sample tube is refrigerated to -196°C while passing
15 helium gas containing nitrogen gas at a concentration of
30 mol% through, thereby causing nitrogen to be adsorbed
on the activated carbon. The sample tube is then heated
to room temperature. The amount of nitrogen separated
out of the sample at this time is measured by a thermal
20 conductivity type detector to regard it as an amount V
adsorbed.

Example 1:

Polyvinylidene chloride powder, zinc chloride and
water were mixed in proportions of 100/40/10 in terms of
25 a weight ratio, and the resultant mixture was then
heated to 730°C at a heating rate of $100^\circ\text{C}/\text{min}$. The
mixture was held at 730°C for 12 hours to conduct the

carbonization and activation of the polyvinylidene chloride powder. The carbonized product thus obtained was washed with water and then dried at 130°C. The dried carbonized product was ground to a particle size of at most 150 mesh to obtain a powdered activated carbon.

The activated carbon thus obtained was used to produce activated carbon electrodes and an electric double layer capacitor in the following manner.

(i) Drying of activated carbon:

The activated carbon was dried at 150°C for 1 minute in a vacuum dryer and then placed in a sample bottle to seal a lid by winding a sealing tape around the lid. This sample bottle was placed in a silica gel-containing desiccator to cool the activated carbon to ordinary temperature (in about 15 minutes).

(ii) Kneading of activated carbon:

Ten parts by weight of conductive acetylene black was ground in a mortar. The dried activated carbon was taken out of the sample bottle, and 80 parts by weight thereof were immediately weighed out and placed in the mortar to well knead it with the conductive acetylene black. After 10 parts by weight of polytetrafluoroethylene (PTFE) powder were then placed in the mortar and stirred, the resultant mixture was kneaded by a pestle to prepare the mixture into a gum-like product. This gum-like product was wrapped with paper used for wrapping of powdered medicine and left to stand for 1

hour in the air to prepare a sample for electrode.

(iii) Production of activated carbon electrode:

The gum-like sample for electrode was chopped with a razor blade, charged into a circular mold and subjected to pressure molding for 5 minutes under a pressure of 200 MPa, thereby producing an activated carbon electrode. The thickness of the activated carbon electrode was measured by a thickness meter to calculate out the volume thereof.

(iv) Fabrication of electric double layer capacitor:

A conductive paste composed of a mixture of conductive carbon black, hydroxymethyl cellulose and water was applied to one side of each of 2 aluminum-made collecting plates. While the conductive paste layer remained a semi-dried state, the activated carbon electrode was struck thereon. Laminates composed of the collecting plate/activated carbon electrode were prepared in the above-described manner. A glass fiber filter (GA-200, product of ADVANTEC Co.) was used as a separator and held between the activated carbon electrode sides of the two laminates. This sandwich structure was incorporated into a PTFE cell. This cell was dried at 150°C for 3 hours in a vacuum dryer and then allowed to cool in a glove box having a dew point of -90°C or lower. An electrolytic solution was then added into the PTFE cell to assemble a single cell type electric double layer capacitor. As the electrolytic

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solution, was used a $(C_2H_5)_4NBF_4$ /propylene carbonate (1 mol/L) solution.

The evaluation results of properties are shown in Table 1.

5 Example 2:

A powdered activated carbon was obtained in the same manner as in Example 1 except that after the carbonized product was ground to a particle size of at most 150 mesh in Example 1, the ground product was
10 treated at 700°C for 2 hours in a nitrogen gas stream. The activated carbon thus obtained was used to produce activated carbon electrodes and an electric double layer capacitor in the same manner as in Example 1 to evaluate their properties. The results are shown in Table 1.

15 Example 3:

Petroleum pitch was oxidized with air at 260°C for 1 hour and then held at 500°C for 1 hour in a nitrogen gas stream to carbonize the pitch, and the carbonized product was then activated with steam of 900°C. The
20 carbonized product thus obtained was ground to a particle size of at most 150 mesh, and the ground product was treated at 700°C for 2 hours in a nitrogen gas stream to obtain a powdered activated carbon. The activated carbon thus obtained was used to produce
25 activated carbon electrodes and an electric double layer capacitor in the same manner as in Example 1 to evaluate their properties. The results are shown in Table 1.

Example 4:

Polyvinylidene chloride powder, zinc chloride and water were mixed in proportions of 100/100/5 in terms of a weight ratio, and the resultant mixture was then
5 heated to 730°C at a heating rate of 100°C/min. The mixture was held at 730°C for 12 hours to conduct the carbonization and activation of the polyvinylidene chloride powder. The carbonized product thus obtained was washed with water and then dried at 130°C. The dried
10 carbonized product was ground to a particle size of at most 150 mesh, and the ground product was treated at 700°C for 2 hours in a nitrogen gas stream to obtain a powdered activated carbon. The activated carbon thus obtained was used to produce activated carbon electrodes
15 and an electric double layer capacitor in the same manner as in Example 1 to evaluate their properties. The results are shown in Table 1.

Comparative Example 1:

Polyvinylidene chloride powder and zinc chloride
20 were mixed in proportions of 100/100 terms of a weight ratio, and the resultant mixture was then heated to 730°C at a heating rate of 100°C/min. The mixture was held at 730°C for 12 hours to conduct the carbonization and activation of the polyvinylidene chloride powder. The
25 carbonized product thus obtained was washed with water and then dried at 130°C. The dried carbonized product was ground to a particle size of at most 150 mesh, and

the ground product was treated at 700°C for 2 hours in a nitrogen gas stream to obtain a powdered activated carbon. The activated carbon thus obtained was used to produce activated carbon electrodes and an electric

5 double layer capacitor in the same manner as in Example 1 to evaluate their properties. The results are shown in Table 1.

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Table 1

	Properties of activated carbon				Evaluation results of durability test				
	Rate of Fs cm ³ /g STP	Oxygen content %	Specific surface area m ² /g	Initial value		After test		Retention of capacity %	Retention of resistance %
				F	Ω	F	Ω		
Ex. 1	18.4	4.1	1600	9.55	1.05	9.00	1.16	94	110
Ex. 2	18.6	1.3	1570	9.52	1.08	9.49	1.11	100	103
Ex. 3	17.1	1.5	1120	8.40	0.45	8.40	0.45	100	100
Ex. 4	24.4	0.9	1580	13.35	0.45	11.69	0.53	88	118
Comp. Ex. 1	32.0	1.0	1610	15.08	1.89	5.77	2.78	38	147

Among the experimental data shown in Table 1, the results of Examples 2 to 4 and Comparative Example 1, in which the oxygen content was low, are illustrated in FIG. 2. As shown in Table 1 and FIG. 2, the rate of FS and the retentions of physical properties have a very good corresponding relationship to each other. The activated carbon low in oxygen content, but high in rate of FS like Comparative Example 1 is poor in durability. On the other hand, the activated carbon relatively high in oxygen content, but low in rate of FS is excellent in durability. As described above, it is understood that activated carbons whose rate of FS is at most 27 cm³/g STP exhibit excellent durability.